FUNDAMENTAL PRINCIPLES FOR EFFICIENT USE OF THE ORBIT/SPECTRUM RESOURCE

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Outline

- Purpose
- EESS network architecture
- Importance of co-channel homogeneity
- Power spectral density
- Modeling typical “efficient modulation” techniques
- Adjacent channel interference
- Conclusions

Preliminary analysis of orbit/spectrum utilization (OS/U) of two EESS networks

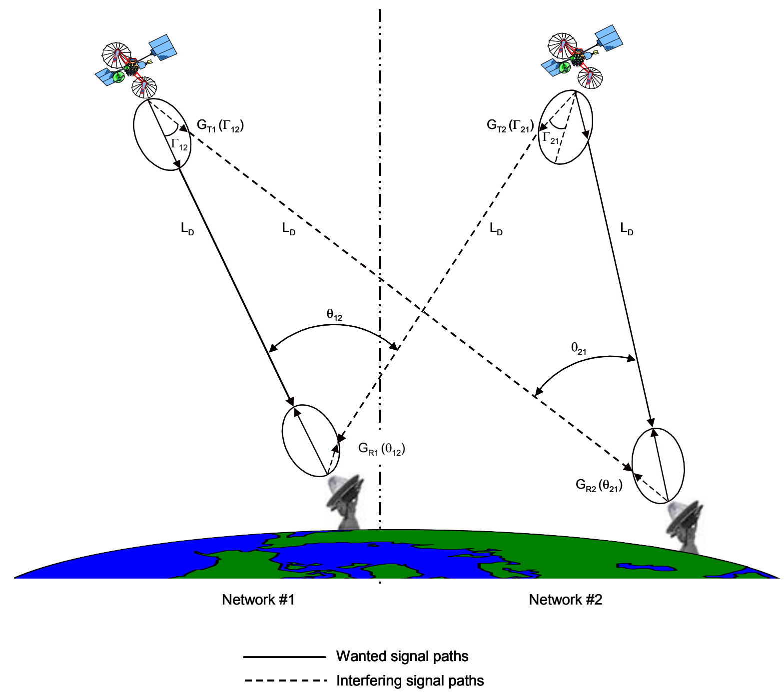
- **Purpose - To establish the approach and to identify system characteristics that determine efficient OS/U.**

Example EESS Network Architecture

- Orbital spacing required to satisfy the sharing criteria is one element of a simple measure of OS/U efficiency. Data throughput per orbital location is another element.

$$I_1(f) = A_{iso}\frac{PSD_2(f)G_{T2}(\Gamma_{21})G_{R1}(\theta_{21})}{4\pi d_{21}^2}$$

$$I_2(f) = A_{iso}\frac{PSD_1(f)G_{T1}(\Gamma_{12})G_{R2}(\theta_{12})}{4\pi d_{12}^2}$$



Note: The main beam of the transmitting antenna on satellite #2 is not pointed towards its earth station.

Importance of Co-Channel Homogeneity

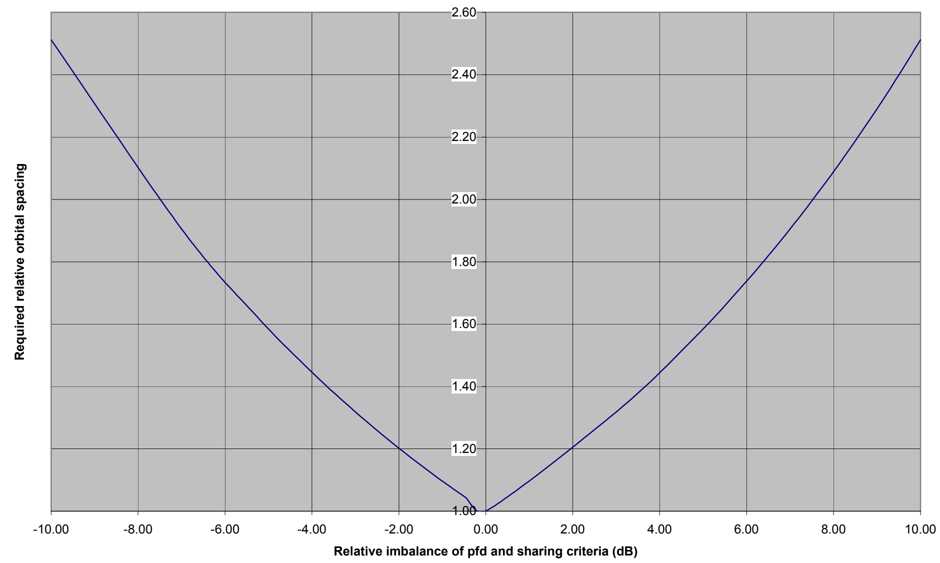
$$I_1(f) = \rho_2(f) G_{R1}(\theta_{21}) A_{iso}$$

$$I_2(f) = \rho_1(f) G_{R2}(\theta_{12}) A_{iso}$$

$$G(\theta) = 1585\theta^{-2.5} \qquad 1^{o} \leq \theta \leq 48^{o}$$

$$\frac{\theta_{12}}{\theta_{21}} = \left[\frac{\rho_1(f)}{\rho_2(f)} \frac{I_1(f)}{I_2(f)} \right]^{1/2.5}$$

$$\Gamma = \max \left\{ \frac{\theta_{12}}{\theta_{21}}, \frac{\theta_{21}}{\theta_{12}} \right\}$$



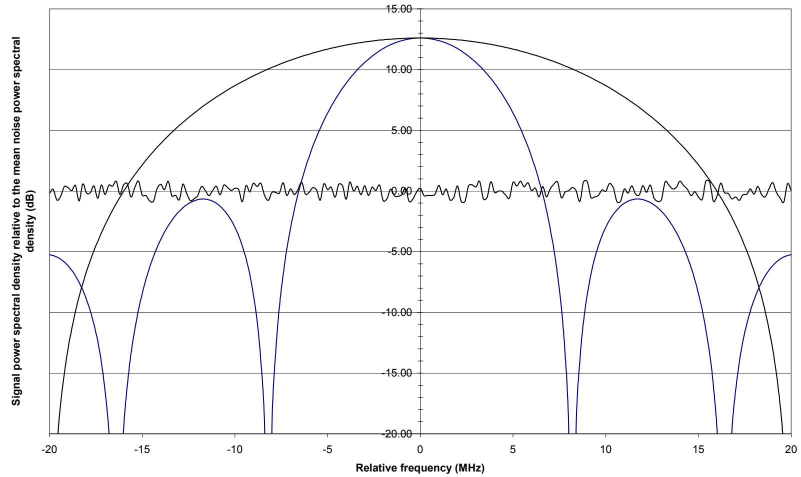
Relative orbital spacing as a function of the relative imbalance of the pfd and sharing criteria.

Maximum Power Spectral Density of M-ary PSK and QAM Signals

$$\frac{S(f)}{\eta_0} = \frac{P_R T_b}{\eta_0}\frac{T_S}{T_b}\frac{\sin^2(\pi f T_S)}{(\pi f T_S)^2} = \frac{E_b}{\eta_0}\frac{T_S}{T_b}\frac{\sin^2(\pi f T_S)}{(\pi f T_S)^2}$$

Effect of data and channel coding on the ratio T_S/T_b for M-ary PSK and QAM

M	**R_{C1} = 0.875 (255,223) RS outer code**	**R_{C2} = 1/2 Convolutional inner code**	**T_S/T_b**
4	No	No	2
4	No	Yes	1
4	Yes	Yes	0.875
8	No	No	3
8	No	Yes	3/2
8	Yes	Yes	1.31
8	TCM	NA	2



Power spectral density of a QPSK signal normalized to the mean noise power spectral density as a function of the off-set frequency: $E_{b1}/\eta_0 = E_{b2}/\eta_0$ = 9.6 dB; T_S/T_b = 2; $1/T_{S1}$ = 8.2 Msps; $1/T_{S2}$ = 20 Msps.

Adjacent Channel Interference in Co-Located Satellites

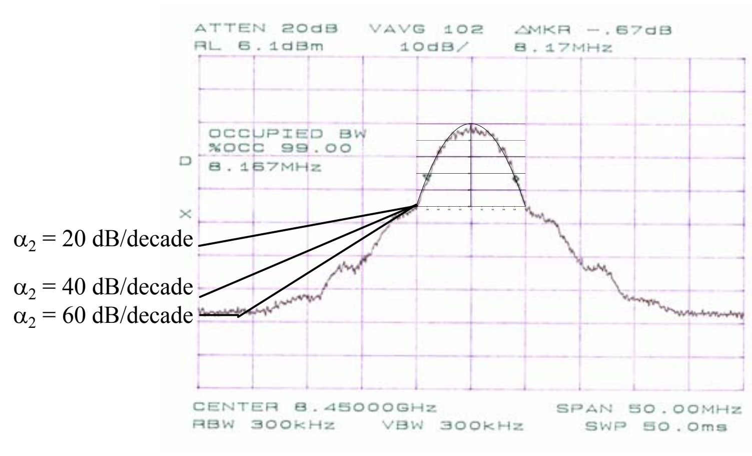
- Modeling the spectral characteristics of typical "efficient modulation techniques."

$$S_1(f) = S(0) - 25\left(|f|T_S\right)^2$$

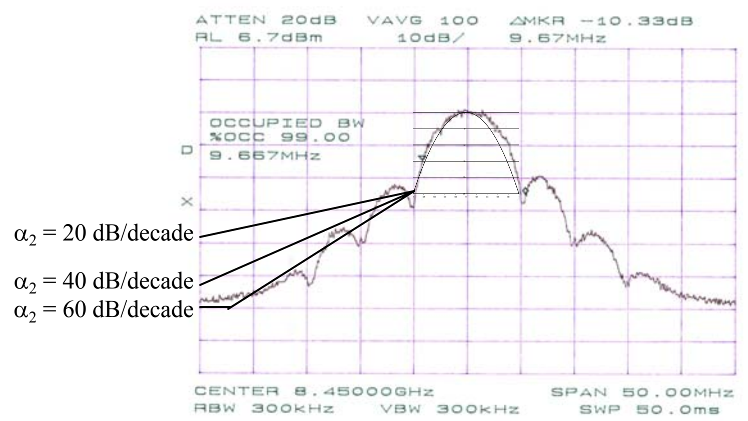
$$S_2(f) = S(0) - 25 - \alpha_2 \log\left(|f|T_S\right)$$

$$S_3(f) = S(0) - 60$$

$$S(f) = \max\{S_1(f), S_2(f), S_3(f)\}$$



a) SRRC-OQPSK



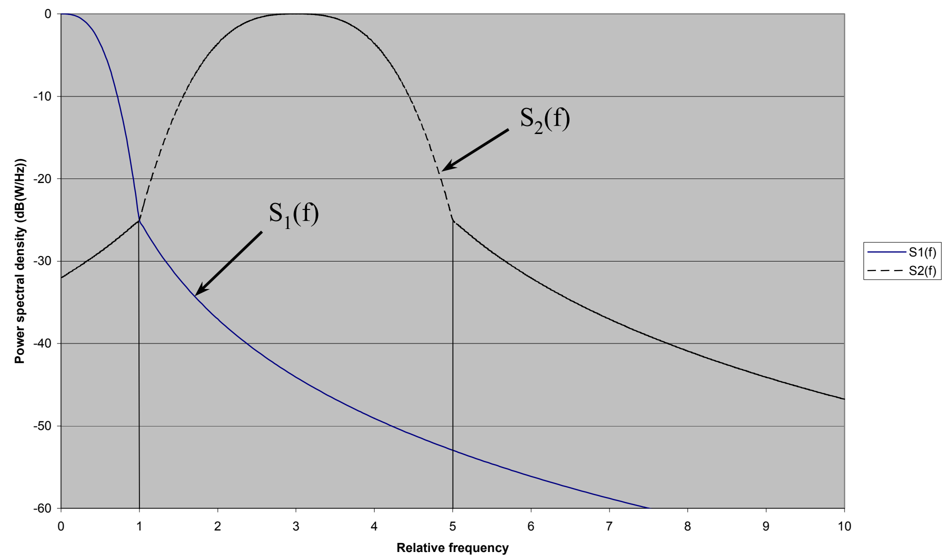
b) Butterworth Filtered OQPSK

Adjacent Channel Interference in Co-Located Satellites (cont.)

$$S_1(f) = S_1(0) - 25 - \alpha_2 \log(|f| T_S)$$

$$I = 3.16 \times 10^{-3} S_1(0) \int_{1/T_{S1}}^{1/T_{S1}+2/T_{S2}} T_{S1}^{-a_0} f^{-a_0} df$$

a_o = 2, 4 or 6, corresponding to
α_2 = 20 dB/decade, 40 dB/decade or 60 dB/decade

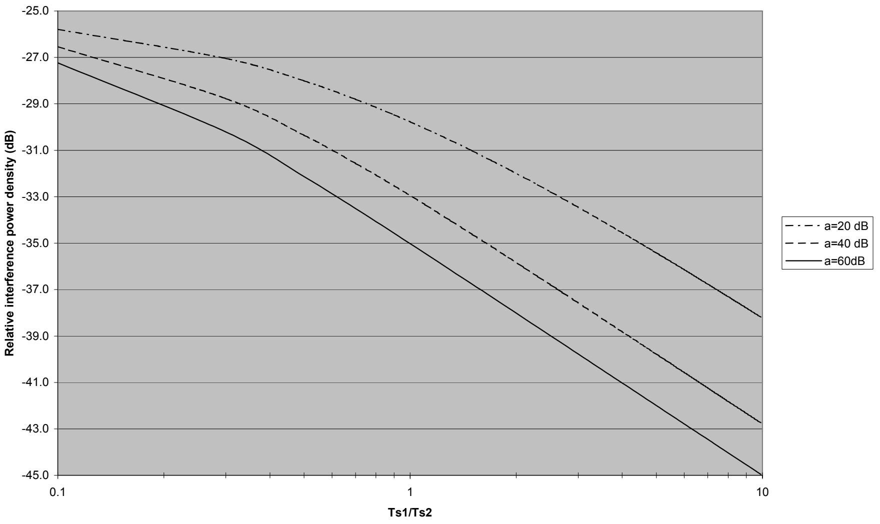


Spectra of an example interference scenario: $S_1(f)$ is the spectrum of the interfering signal; and, $S_2(f)$ is the spectrum of the desired signal.

$$\gamma = \frac{\eta_{2i}}{S_1(0)} = \frac{3.16\times 10^{-3}}{2(a_0 - 1)} \frac{T_{S2}}{T_{S1}} \left[1 - \frac{1}{\left(1 + 2\frac{T_{S1}}{T_{S2}}\right)^{a_0 - 1}} \right]$$

$$\frac{\eta_{2i}}{\eta_0} = \frac{E_{b1}}{\eta_0} \frac{T_{S1}}{T_{b1}} \gamma$$

$$10\log(\Delta) = 10\log(1 + \eta_{2i}/\eta_0)$$



Equivalent uniformly distributed interference power spectral density in the desired signal channel from the emissions in the adjacent channel normalized to the maximum power spectral density in the interfering channel (γ): T_{S1} = symbol duration in the interfering channel; and, T_{S2} = symbol duration in the desired channel.

Adjacent Channel Interference in Co-Located Satellites (cont.)

Degradation of E_b/η_0 for uncoded QPSK[JEM1].

	Degradation (dB)					
	α_2 = 20 dB/decade		α_2 = 40 dB/decade		α_2 = 60 dB/decade	
T_{S1}/T_{S2}	E_{b1}/η_0= 12 dB	E_{b1}/η_0= 17 dB	E_{b1}/η_0= 12 dB	E_{b1}/η_0= 17 dB	E_{b1}/η_0= 12 dB	E_{b1}/η_0= 17 dB
0.1	0.35	1.02	0.30	0.87	0.25	0.75
0.5	0.21	0.64	0.13	0.38	0.08	0.26
1.0	0.14	0.44	0.07	0.22	0.04	0.14
2.0	0.09	0.27	0.04	0.11	0.02	0.07
5.0	0.039	0.123	0.014	0.045	0.009	0.027
10.0	0.021	0.065	0.007	0.023	0.004	0.014

Adjacent channel interference is not a significant factor affecting orbit/spectrum utilization of homogeneous EESS networks.

Conclusions from the Preliminary Study

- The following are the significant general results of this preliminary study:
  - the spectral power flux-density is a fundamental parameter affecting the performance of the desired link and the interference to other links;
  - since E_b/η_0 is related to the spectral power-flux density, it is also a fundamental parameter affecting the performance of the desired link and the relative interference to other links;
  - for a given set of link characteristics, the spectral power-flux density will be independent of the capacity of the link;
  - the noise temperature of the receiving earth station is a fundamental parameter affecting the performance of desired link and to quantifying the degradation to the link performance as a result of interference received from other links; and,
  - the power spectral density of the continuous spectrum of at least three of the efficient modulation techniques may be modeled in a very simple way.
- For satellites separated in the orbital plane that are using co-channel carriers:
  - the most efficient use of the orbit/spectrum resource occurs when the networks are homogeneous, that is, the off-axis gain of the earth station receiving antenna, and, the ratio of the interference criterion required by each receiving earth station and the spectral power-flux density produced on the surface of the earth at each receiving earth station for each network are identical; and,
  - a 7.5 dB imbalance in the homogeneity of two EESS networks will lead to a factor of 2 increase in the orbital spacing.
- For co-located satellites that are using carriers operating on adjacent channels:
  - the adjacent channel interference from a homogeneous pair of co-located satellites degrades the performance margin of the desired link by less than 0.004 dB up to about 1 dB depending on the particular values for E_b/η_0, the ratio of the duration of the interfering and desired symbol, and, the rate of attenuation (i.e., 20 dB/decade, 40 dB/decade or 60 dB/decade) of the power spectral density in the region outside twice the symbol rate bandwidth. The 1 dB degradation occurs when the high capacity carrier interferes with a low capacity carrier in the adjacent channel, for example, a 35 Mbps carrier receiving interference from a 350 Mbps carrier.